Development of Refractory Oxide- and Glass Ceramic-YSZ Dual Layer TBCs

Kang N. Lee (kang.n.lee@lerc.nasa.gov; 216-433-5634)
Surenda Tewari (tewari@csvax.csuohio.edu; 216-523-7342)
Department of Chemical Engineering
Cleveland State University
1960 E. 24th Street
Cleveland, OH 44115

Abstract

Development of advanced thermal barrier coatings (TBCs) is the most promising approach to increasing the efficiency and performance of advanced land-based gas-turbine engines by enhancing the temperature capability of hot section metallic components. Spallation of the yttria-stabilized zirconia (YSZ) top coat, induced by the oxidation of the bond coat, coupled with the thermal expansion (CTE) mismatch strain, is considered to be the ultimate failure mode for current state-of-the-art TBCs. Therefore, it is a logical step to enhance the oxidation resistance of the bond coat to improve the durability of current TBCs.

Enhanced oxidation resistance of current TBCs can only be achieved by reducing the oxygen conductance of TBCs below that of alumina scale. Therefore, approaches to enhancing the oxidation resistance of current TBCs must include incorporating an oxygen barrier with its oxygen conductance lower than that of alumina scale. This can be accomplished either by applying a ceramic coating with its oxygen conductance lower than that of alumina or by reducing the oxygen conductance of alumina scale itself. To remain effective, the barrier layer must ideally be crack free, but more realistically, be intimately bonded to the substrate with only occasional fine cracks.

We propose new classes of ceramic materials as an oxygen barrier between the bond coat and the YSZ top coat. These are mullite, lanthanoid silicates (La_2SiO_5, Sm_2SiO_5, Y_2SiO_5), glass ceramics (MAS, CAS, BAS). The oxygen conductivity of mullite is believed to be similar to that of silica. (Alumina and silica are the two most protective oxides at high temperatures and silica is slower growing than even the best protective alumina scale at T>1,000 °C.) Since the oxygen conductance is inversely proportional to thickness (i.e., conductance = conductivity/thickness), if the coating thickness is greater than that of alumina scale, the oxygen conductance of mullite and Y_2SiO_5 will be lower than that of alumina scale. The oxygen conductivity of La_2SiO_5, Sm_2SiO_5, and glass ceramics is not known; however, glass ceramics showed potential as an oxygen barrier when applied on SiC ceramics. Another potential benefit of the proposed coating is the enhanced adherence of TBCs because of the formation of alumino-silicate scale at the coating/bond coat interface, through a chemical reaction between these refractory oxides and alumina scale. The CTE of some of these ceramics (La_2SiO_5, Sm_2SiO_5) is similar to or higher than that of YSZ, while the others (mullite, Y_2SiO_5, glass ceramics) have a lower CTE than YSZ. But even the low CTE

may be relatively unimportant to the overall CTE of the system if a high YSZ/new ceramic thickness ratio is employed.

We demonstrated the feasibility of high quality coatings of these new ceramics by air plasma spraying and their efficiency as an oxygen barrier on SiC substrates. Coatings maintained the oxygen barrier efficiency, even though there were fine cracks through the thickness, because the alumino-silicate scale imparted excellent chemical bonding with the substrate. We have also successfully applied mullite/YSZ and CAS/YSZ on CMSX-4+Y substrate suing HVOF. We are in the process of optimizing the spray parameters and annealing condition for the best adherence and oxidation resistance.

The new coatings will be characterized for adherence, oxidation resistance, CTE from RT to 1,200 °C, and thermal conductivity. Furnace testing will be used to examine long-term oxidation kinetics, phase stability, chemical stability, and thermal durability at various temperatures and cyclic conditions. Based on these results, two optimum coating combinations will be selected for further evaluation in the burner rig.

Acknowledgment

The research is being performed for the U.S. Department of Energy's Federal Energy Technology Center under contract no. 96-01-SR042, with Cleveland State University, Cleveland, Ohio 44115, phone: 216-687-3630, fax: 216-687-9214, contract period: June 13, 1997 to June 12, 1998. The COR is Daniel B. Fant.

Development of Refractory Oxide- and Glass Ceramic-YSZ Dual Layer TBC's

Kang N. Lee and Surendra Tewari

Dept. of Chem. Eng.

Cleveland State University

Cleveland, OH

Research Area

- Materials

Objective

- Develop TBC’s with enhanced oxidation resistance and adherence for advanced land-based gas turbine engines.

Relevance

- TBC’s with enhanced oxidation resistance and adherence provide longer lifetime and higher temperature capability, which in turn increase the efficiency and performance of gas turbine engines.

Approach

- Intermediate oxide layer between YSZ and Bond coat
  - slow scale growth above 1000^{o}C (slower than alumina)
  - improved adherence & good chemical compatibility
- Selection of oxides for the intermediate layer

Oxide*	**Mullite, CAS, BAS, MAS**	**Y_2SiO_5**	**Sm_2SiO_5, La_2SiO_5**
CTE ($10^{-6}/^{o}C$)	Low (4 -6)	Medium (8)	High (9-12)
Oxygen Conductivity	reduced the growth rate of silica when applied on SiC	similar to alumina	unknown (similar to Y_2SiO_5?)

* C: CaO, B: BaO, M: MgO, A: Al_2O_3, S: SiO_2

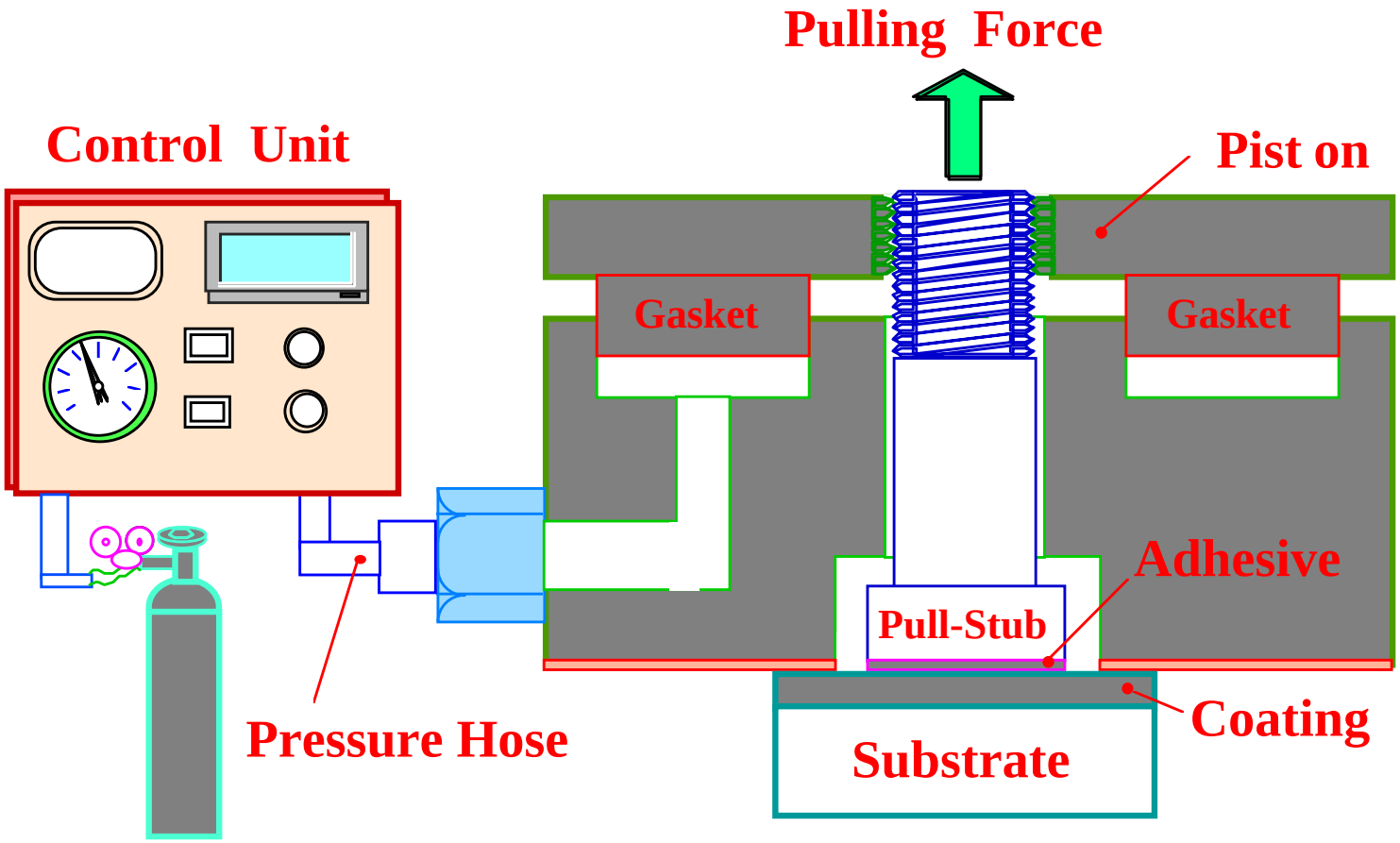
Approach (cont.)

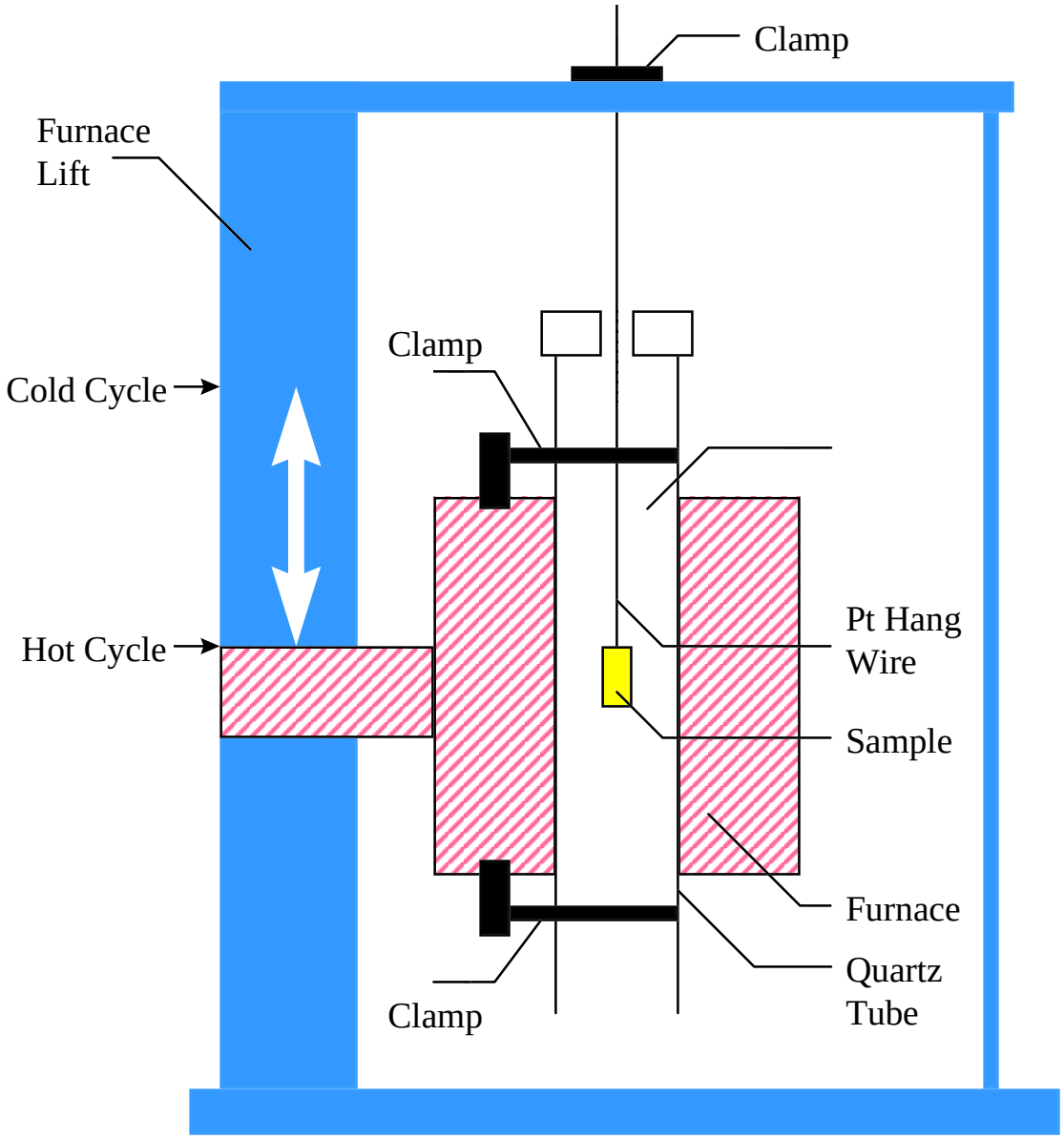
- Select spray technique
  - HVOF (primary)
  - APS with heated substrate (backup)
- Select substrates
  - CMSX4+Y (NASA, Westinghouse, Solar Turbines)
  - Mar M247 (Solar Turbines)
  - Rene’N5 (GE)

Approach (cont.)

- Select bond coat
  - MCrAlY (low pressure plasma spray)
  - PtAl (for Rene'N5, CVD)
- Select Testing & Evaluation Technology
  - oxidation kinetics
    - furnace cycling, burner rig
  - adhesion test
  - CTE
  - thermal conductivity

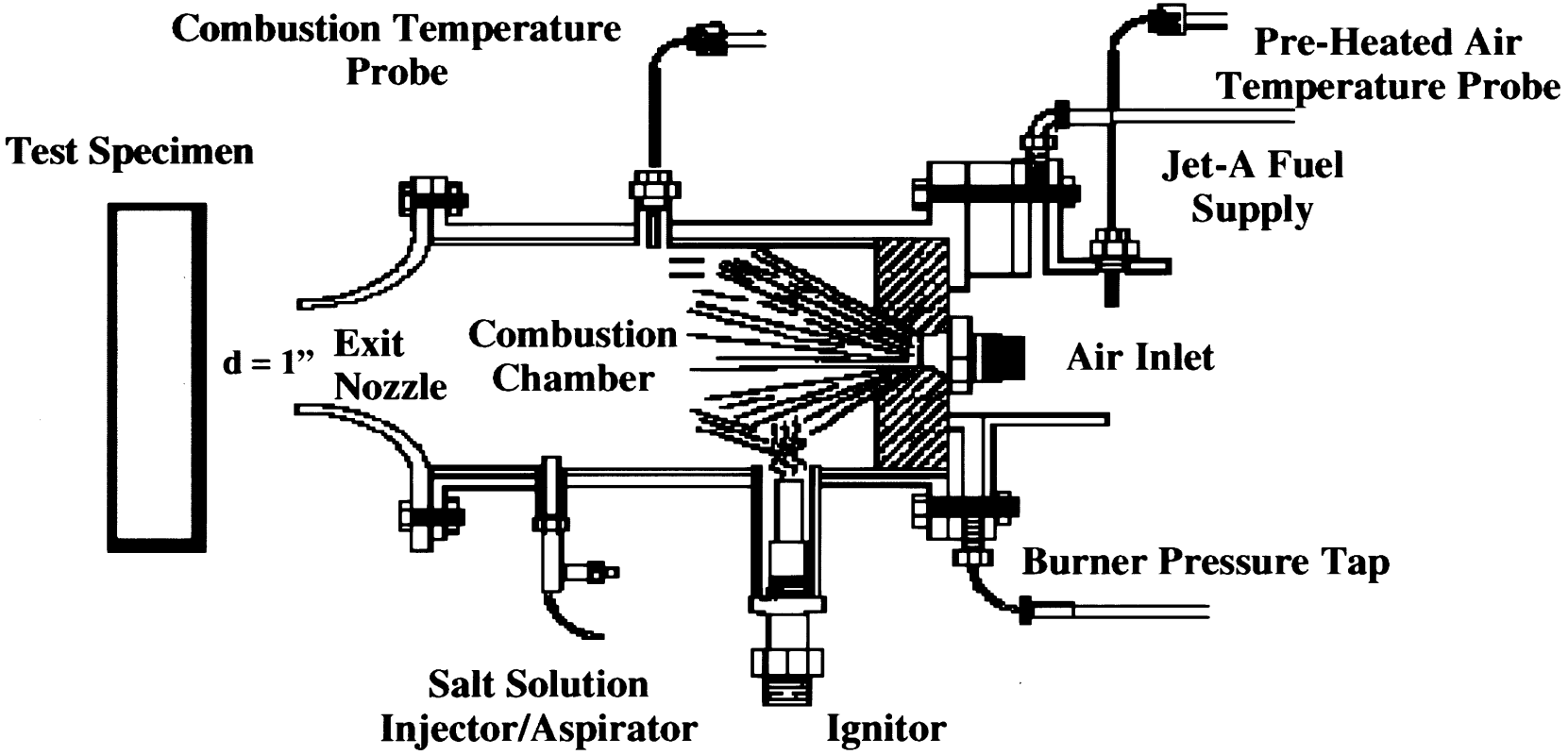
Pneumatic Coating Adhesion Tester





Cyclic Furnace

Mach 0.3 Burner Rig



Accomplishments (7 - 9/97)

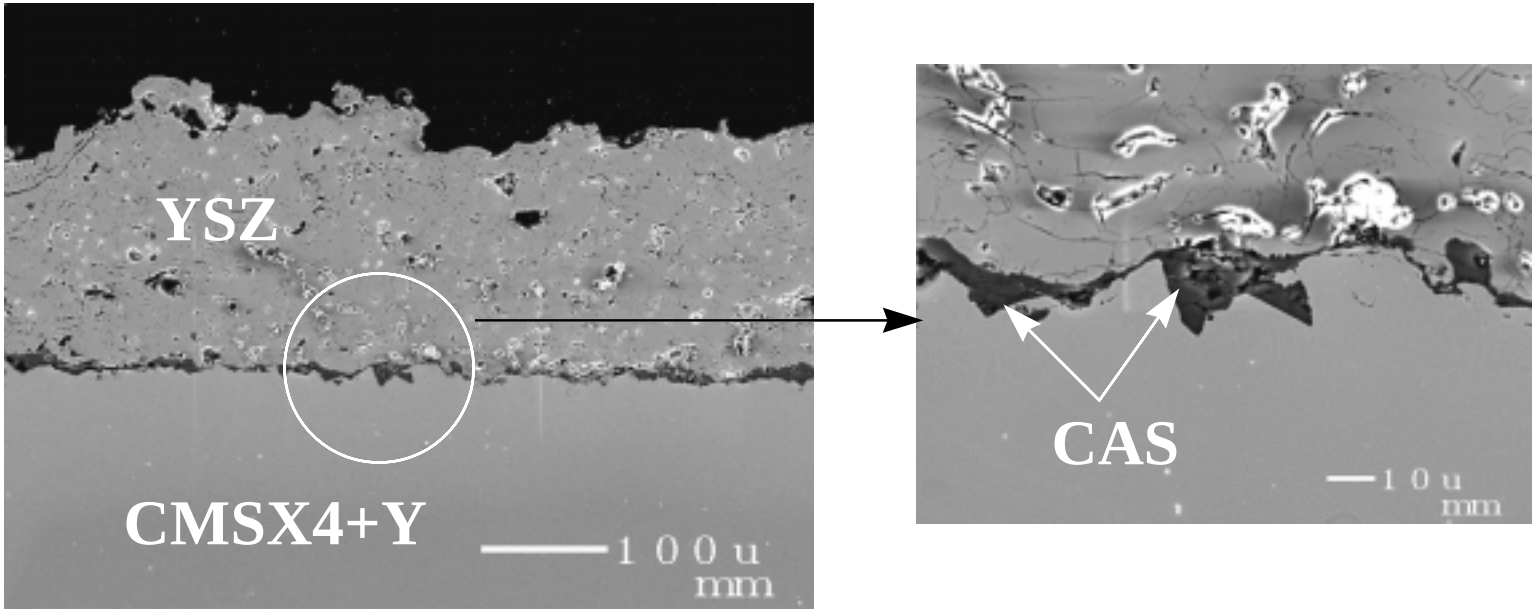
- Spray powder development
  - **on hand :**low and medium CTE oxides
  - **under development:** high CTE oxides
- Spray parameter development
  - **HVOF**
    - low CTE oxide spraying under development
  - **APS**
    - low CTE oxide spraying established

Key Accomplishment

- CAS coating successfully applied on CMSX4+Y (no bond coat) by HVOF
  - **CAS/CMSX4+Y interface showed better adhesion than YSZ/CMSX4+Y interface** (4h-1150^{o}C in Ar-5% H_2)
    - YSZ-coated CMSX4+Y fractured at the YSZ/CMSX4+Y interface (adhesive failure), while CAS/YSZ-coated CMSX4+Y fractured at or near the CAS/YSZ interface (mixed cohesive/adhesive failure).
    - Both coatings fractured at 1400 psi

CAS/YSZ-Coated CMSX4+Y

after 4h-1150°C in Ar-5%H_2

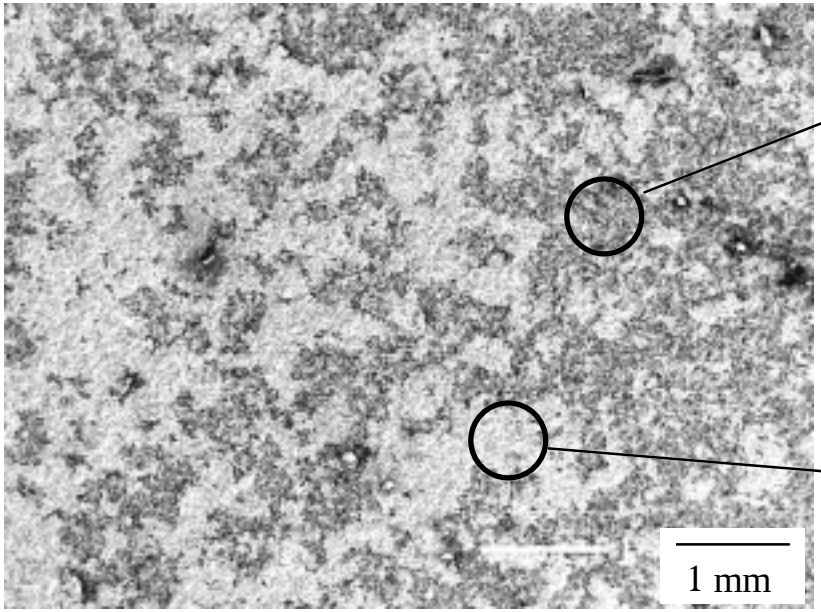


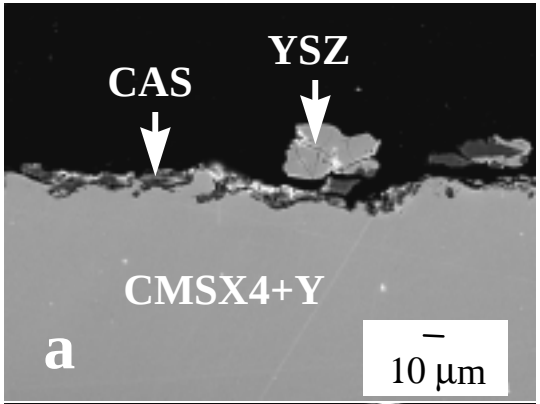
- CAS adherent after annealing
- CAS thickness initially not uniform

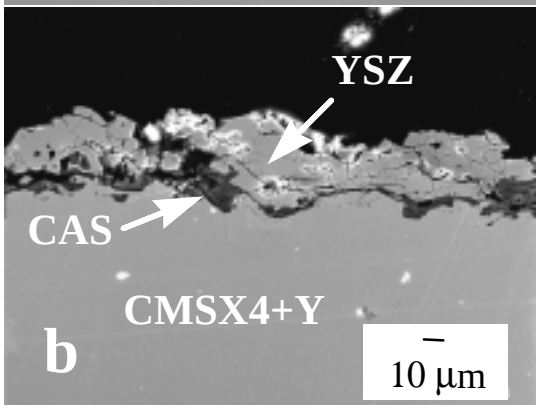
CAS/YSZ-Coated CMSX4+Y

4h-1150°C in Ar-5%H_2, fractured by adhesion test

Top view of the fractured surface



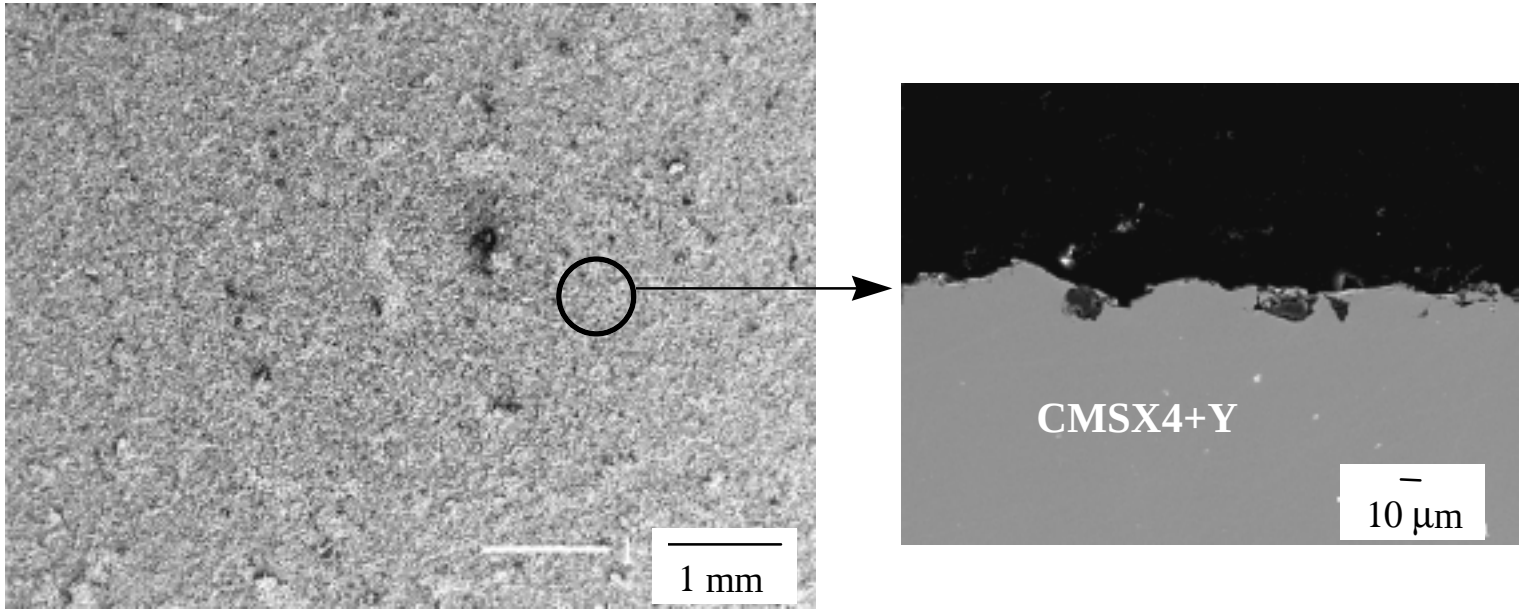




a. Fractured at the YSZ/CAS interface
b. Fractured in the YSZ near the YSZ/CAS interface

YSZ-Coated CMSX4+Y

4h-1150°C in Ar-5%H_2, fractured by adhesion test



- Fractured at the YSZ/CMSX4+Y interface

Collaboration

- INDUSTRY
  - **Westinghouse, Solar Turbines, GEAE**
  - will provide superalloy substrate and guidance on testing and evaluation, and will support the transition of successful coatings to application in the industrial gas turbine through full scale rig and/or engine tests.
- NASA Lewis
  - will provide HVOF/plasma spray and burner rig facilities and initial CMSX4+Y specimens

Future Activities for FY98

- Continue to develop HVOF spray parameters for low CTE oxides
- Develop HVOF spray parameters for medium and high CTE oxides
- Investigate various annealing conditions for best adhesion
- Evaluate oxidation kinetics using furnace cycling tests